Atwood's Machine

Equipment:

1	Photogate	ME-9498A
1	Pulley (part of CI-6691)	ME-9450A
1	Mounting Rod	SA-9242
1	Table Clamp	ME-9472
1	Multi-Clamp	ME-9507
1	90 cm Rod	ME-8738
1	Braided String	SE-8050
1	Mass and Hanger Set	ME-8979
1	No-Bounce Pad	SE-7347

Introduction

The purpose of this lab is to study an Atwood's Machine apparatus, built with a PASCO Super Pulley. The Photogate is used to measure the velocity of both masses as one moves up and the other moves down. The slope of the graph of velocity vs. time is the acceleration of the system. Careful measurement when there is no net force allows the student to compensate for friction.

Figure 1: m_1 (on right) > m_2

The Table Clamp is used to support the 90 cm Rod. The yellow No-Bounce Pad is used to protect the falling Mass Hanger when it reaches the table. The Photogate must be plugged into Digital Input #1.

Setup

Building the Apparatus:

1. Fasten the table clamp and the 90 cm rod to the edge of the table as shown in Figure 1.

2. Attach the pulley to the photogate using the mounting rod as shown in Figure 2.

3. Use the multi-clamp (see Fig. 3) to fasten the photogate to the vertical rod. Plug the photogate cord into Digital Input #1.

4. Position the yellow No-Bounce Pad (see Fig. 1) below the photogate to protect the falling mass hanger when it reaches the table.

5. Cut a 1.2 m piece of the braided string and tie loops on each end to hold a mass hanger. Loop the string up and over the pulley as shown in Figure 3.

6. Add a single 100 g mass and a single 20 g mass to one mass hanger (5 g) for a total mass of 125 g. We will call this mass hanger m_1. To a second mass hanger (call it m_2) add a single 100 g mass for a total of 105 g. Hang the masses on the string over the pulley.

7. Adjust the height of the pulley or length of string so that when mass hanger m_1 is touching the No-Bounce Pad, mass hanger m_2 is a few centimeters below the pulley. The Photogate should be horizontal so the string does not pull sideways on the pulley.

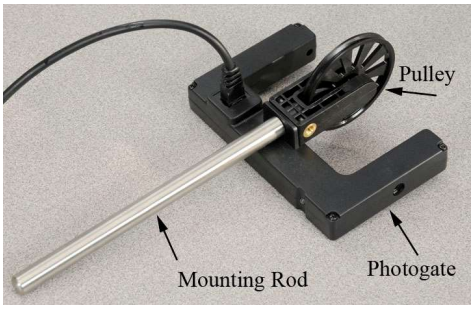

Figure 2: Pulley and Photogate

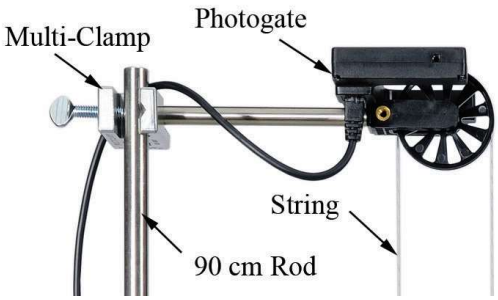

Figure 3: Rods and Clamp

Theory

An Atwood's Machine consists of two unequal masses connected by a single string that passes over an ideally massless and frictionless pulley as in Figure 4. When released, the heavier object accelerates downward while the lighter object accelerates upward.

The free-body diagrams (Fig. 5) show the forces acting on each of the masses. T is the tension in the string. With $m_1 > m_2$, m_1 is descending mass and m_2 is the ascending mass. The magnitude of the acceleration, a, is the same for each mass, but the masses accelerate in opposite directions. We adopt the convention that down is positive. Applying Newton's 2nd Law ($F_{net} = ma$) to the descending mass, m_1, gives

$$m_1 g - T = m_1 a \ .$$

Applying Newton's 2nd Law to the ascending mass, m_2, gives

$$m_2 g - T = m_2(-a) \ .$$

Eliminating T between the two equations and solving for the acceleration yields:

$$a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) g \qquad \text{Eqn. (1)}$$

Shoe that Equation (1) reduces to the expected result in the following limiting cases. Explain why each case is expected:

Case 1: $m_1 = m_2$

Case 2: $m_1 = 0$

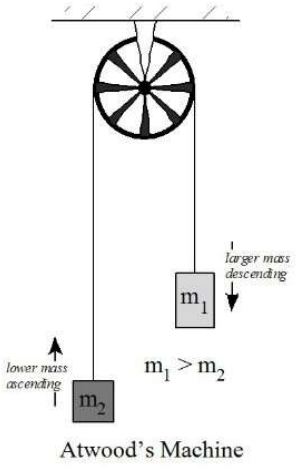

Figure 4: Atwood's Machine

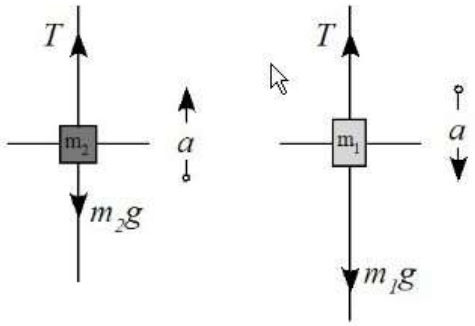

Figure 5: Free Body Diagrams

Procedure

1. In PASCO Capstone, create a graph of Linear Speed vs. Time.

2. Move m_2 to its lowest point. Click on Record. Release m_2.

3. Stop recording just before m_1 strikes the pad.

4. The masses may touch as they pass each other. If so, repeat the run. You can delete unwanted runs using the Delete Run feature in the control palette below. You should see a linear region on the speed graph as the masses move freely.

5. Select a Linear Curve Fit from the graph tool palette. What is the physical meaning of the slope? Does it have units?

6. Using Eqn. 1, calculate the theoretical value for the acceleration.

7. Calculate the percent difference between the experimental and theoretical value.

Accounting for Friction

8. Add an additional 20 g mass to m_2. The two masses should now balance. If there were no friction, and we gave m_1 a push downward, it would continue at constant speed.

9. Move m_1 to its highest point. Click on Record. Give m_1 a gentle push downward and release it. You should see that the speed is decreasing.

10. Add 1 g to mass m_1 and repeat the measurement. Does the speed still decrease?

11. Using the 1/2 g, and 1 g masses, adjust the mass of m_1 until the speed stays as constant as possible.

12. Record this added "frictional" mass. The weight of this mass is the extra force needed to overcome the frictional force, and thus does not contribute to the acceleration. To account for friction, this mass should be subtracted off from the actual value of m_1.

Analysis

1. Re-calculate the theoretical acceleration using Eqn (1), but subtract off the frictional mass from m_1 in the numerator.

2. Compare your measured value for the acceleration to this adjusted theoretical (accepted) value using the % error calculation.

$$\%\ error = \frac{Measured - Accepted}{Accepted} \times 100\%$$

3. How did the correction for friction affect your final results?